Optimization of the Compressed Air-Usage in South African Mines

Ali Hassan, Khmaies Ouahada, Tshilidzi Marwala and Bhekisipho Twala
Department of Electric and Electronic Engineering Science, University of Johannesburg, South Africa
Email: Alinabeal99@yahoo.com,{kouahada, tmarwala, btwala}@uj.ac.za

***Abstract*—The critical electricity supply in South Africa has necessitated the implementation of demand-side management (DSM) projects. Load shifting and energy efficiency projects were introduced on mining sectors to reduce the electricity usage during day peak time. As the compressed air networks is using a large amount of mines' electricity, we investigate in this paper the possibility of improving and optimizing the compressed air usage at two different mines to reduce the electricity consumption on the compressed air system.**

***Index Terms*—Demand Side Management, Energy efficiency, Mines, Compressed air.**

I. Introduction

The increase in the world population and economic development has led to an increase in energy demand [1]. This increase in demand was also experienced in developing countries such as South Africa [2], where the use of the fossil fuels to generate energy is significantly increased.

Due to South Africa's significant growth in electricity consumption, capacity problems have been experienced and resulting in significant levels of load shedding [3]. The mining industry is a major electricity consumer in South Africa, consuming approximately 23% of the total generated power [4]–[5].

In order to overcome these capacity problems, demand-side management (DSM) and energy efficiency (EE) have become increasingly important. The use of the energy efficient technologies leads to both the reduction of energy demand and greenhouse gas emissions due to the decreased stress on power generating plants [6].

In 1992, Eskom, the main South African electricity supplier, has launched a DSM program in accordance with regulations drawn up by the department of minerals and energy and the national energy regulator of South Africa (NERSA). A similar program was first implemented in the early 80's of the last century in the United States of America and later on in Europe with a great success [7].

DSM plays an important role in reducing the maximum demand for electricity, particularly during peak times in South Africa [8].

Two different South African mines are used as case studies where two proposed control techniques are introduced. These two control philosophy differ between the different mines because of the mines' different specifications, existing infrastructure and layout. Low cost was highly considered to implement the proposed techniques.

Mine shaft's status, whether they are productive or non-productive, also taken into consideration our work and plays an important rule to decide the best control philosophy, due to restrictions from the mine management on implementing new infrastructure on the productive shafts are more than the nonproductive.

Several investigations were conducted on different mines in South Africa to determine the potential energy (MW) and money savings target by optimizing the air usage. In this paper and in view of number of pages restrictions, we will present and discuss only two cases of two different mines.

The paper is organized as follows. Sections II and III will be discussing two cases from two different mines in South Africa and present the proposed control philosophy techniques to reduce energy consumption with no effect on the mine's production. We conclude in Section IV with the presentation of the achieved results.

II. CASE STUDY ONE: MINE A

A. Review

Our first case of study is a South African gold mine, named as Mine A, which is considered as a deep gold mine and consisting of three shafts, denoted by Sht1, Sht2 and Sht3. This mine besides producing gold is also producing Uranium. We investigate in this section the number of compressed air consumers on all the three shafts that will be accounted for including their minimum requirements for compressed air. The knowledge of how the available compressors are utilized will provide an understanding of how to optimize the compressed air usage.

B. Mine A Layout

The three shafts air network reticulation layout at the mine A are shown in Fig. 1. The first shaft, sht1, consists of four mining levels and a loading box level, whereas the second shaft, sht2, consists of five mining levels and a loading box level. Finally the third shaft, sht3, consists of five mining levels and two loading box levels.

It is important to mention that all compressors on each shaft have a guide vain controller installed that is working properly.

Fig. 1 shows a detailed layout of the compressed air reticulation of the mine A shaft ring. The main compressed air line connecting the shafts has an average diameter of 600mm.

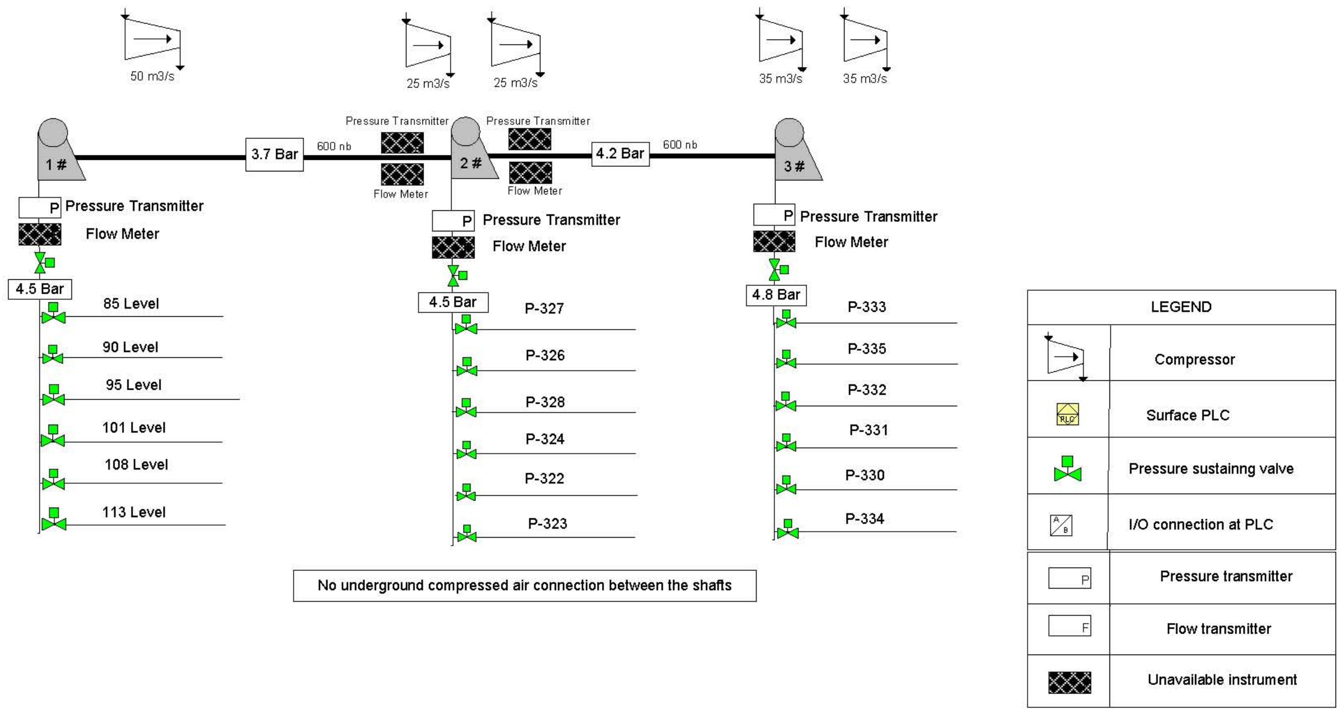

Fig. 1. Mine A air network and mining levels layout

Table I provides information on the compressors in the mine A ring.

The air pressures for the mine A air ring were logged for one month to determine the baseline. The pressure measurements used to determine the baseline were obtained from the delivery side of the compressors on each shaft.

C. Proposed control philosophy

As mentioned before, the mine has five compressors, where usually two are running. The mine is alternating between the compressors.

The idea is to verify which three compressors will be used often at the mine A ring. The supervisory control and data acquisition (SCADA) system will be installed to control these compressors. The SCADA will also communicate with a programmable logic control (PLC) installed in the compressor's house at each shaft. Each shaft's PLC will communicate via a radio link. The system will control the pressure set points of the guide vain at each compressor. The system will increase these set points in the time of the highest demand and it will lower the set points the rest of the day. This will allow the compressors to cut back in delivery pressure which decreases the power consumption and realize the savings.

A variety of pressure tests were conducted on each compressor. These tests would be a simulation of the control philosophy that will be implemented, and to determine more accurately the minimum required air pressure for the shafts. It is proposed that a mass flow meter is to be installed on the main air pipe at each shaft; this will provide accountability for each shaft on the amount of compressed air consumed. Pressure sustaining valves will also be installed on the main air pipe at each shaft to control compressed air supply. The entire installed infrastructure will be controlled from the surface by a SCADA system.

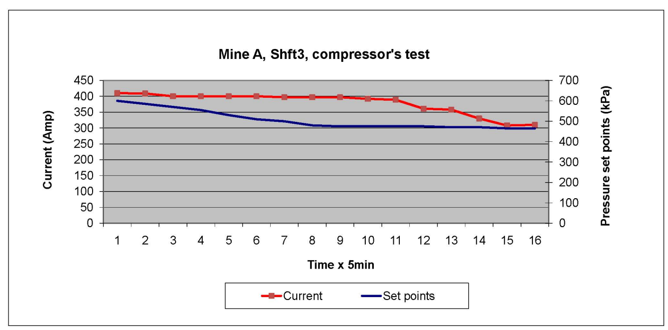

Fig. 2. Pressure test for the shaft, shft1, compressor

The first test was conducted on the Sulzer compressor at the third shaft, shft3. The compressor was shut down and completely stopped at 12:00pm. The measurements were taken at an interval of time of 5min during a period of 80min as shown in Fig. 2. We see clearly that the pressure, which related to shaft three delivery column, started gradually dropping down to reach 400 kPa at as 12:40pm.

TABLE I
MINE A RING COMPRESSORS INFORMATION

Compressor Name	Compressor Type	Installed Capacity (kW)	Guide Vane Control	PLC On/Off
Comp1 (Sht1)	DEMAG	4500	Yes	No
Comp2 (Sht2)	GHH	4300	Yes	No
Comp3 (Sht2)	BBC	5250	Yes	No
Comp4 (Sht3)	SULZER	5300	Yes	No
Comp5 (Sht3)	SULZER	5300	Yes	No

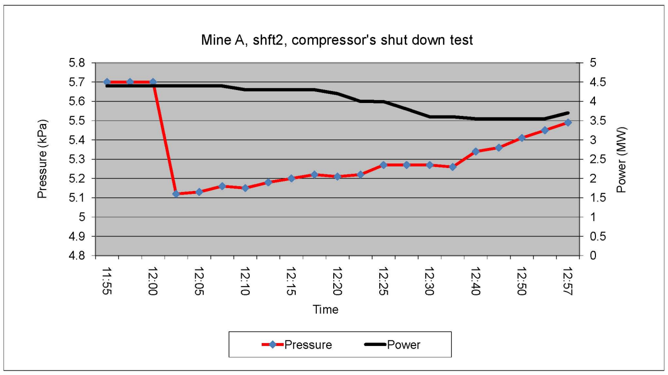

Fig. 3. Guide vain test conducted on the GHH compressor at shft2

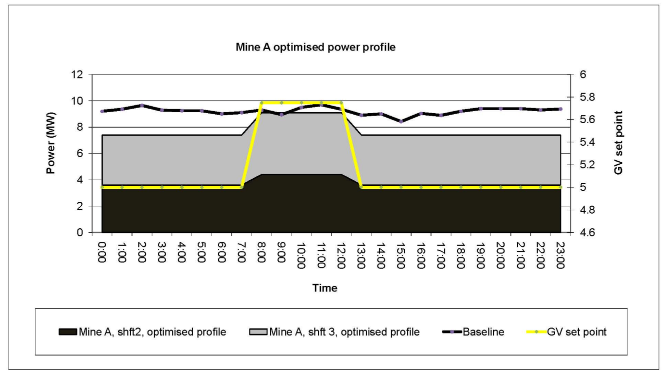

Fig. 5. Mine A optimized power profile

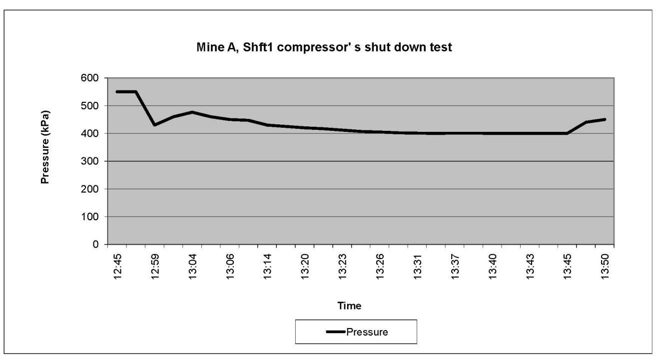

Fig. 4. Pressure test for the mine A, shft1 compressor

It can be noticed from Fig. 2, that by reducing the pressure set points, the current consumption drops. This, in fact will decrease the power consumption.

The second test shown in Fig. 3 was conducted on the GHH compressor at mine A shaft, shft2. This compressor is often to be ran and the test was to close the guide vain to zero and measure the power reduction. This test shows the ability of the compressor to reduce the power consumption once the guide vain is closed.

The third test was conducted on the sht1 Demag compressor as shown in Fig. 4.

This test lasted for almost an hour and the pressure dropped to 400 kPa. It is important to mention that this compressor was not included in determining the over all optimized power profile because the mine is not running it currently.

After we conducted the previous tests, we became able to obtain the savings and determine what the optimized power profile is going to be. Fig. 5 shows the optimized baseline after combining all the shafts optimized power profiles. The original baseline was developed using data which have been collected for a period of one month by installing power and current loggers on the compressors.

Compressed air is highly demanded during the drilling periods. The drilling period for this specific mine shafts is between 8:00 to 13:00. The drilling hours specified by the mine is between 08:00 to 13:00, where savings are not achieved. Fig. 5 shows the kW savings that can be achieved by optimizing air delivery. Once the infrastructure is in place and air consumers are identified, air-leak detection and fixing will improve the energy savings. The savings of 1.135 MW was achievable.

III. CASE STUDY TWO: MINE B

A. Review

The second case of study is also a deep gold mine named as Mine B, which consists of two main shafts, sht1 and sht2. The second shaft, sht2, has terminated production. The first shaft, sht1, is fully productive. Compressed air is being used in production and the mine is consuming large amount of air, which led to an increase of the electric bill due to the fact that the compressors are running in full capacity.

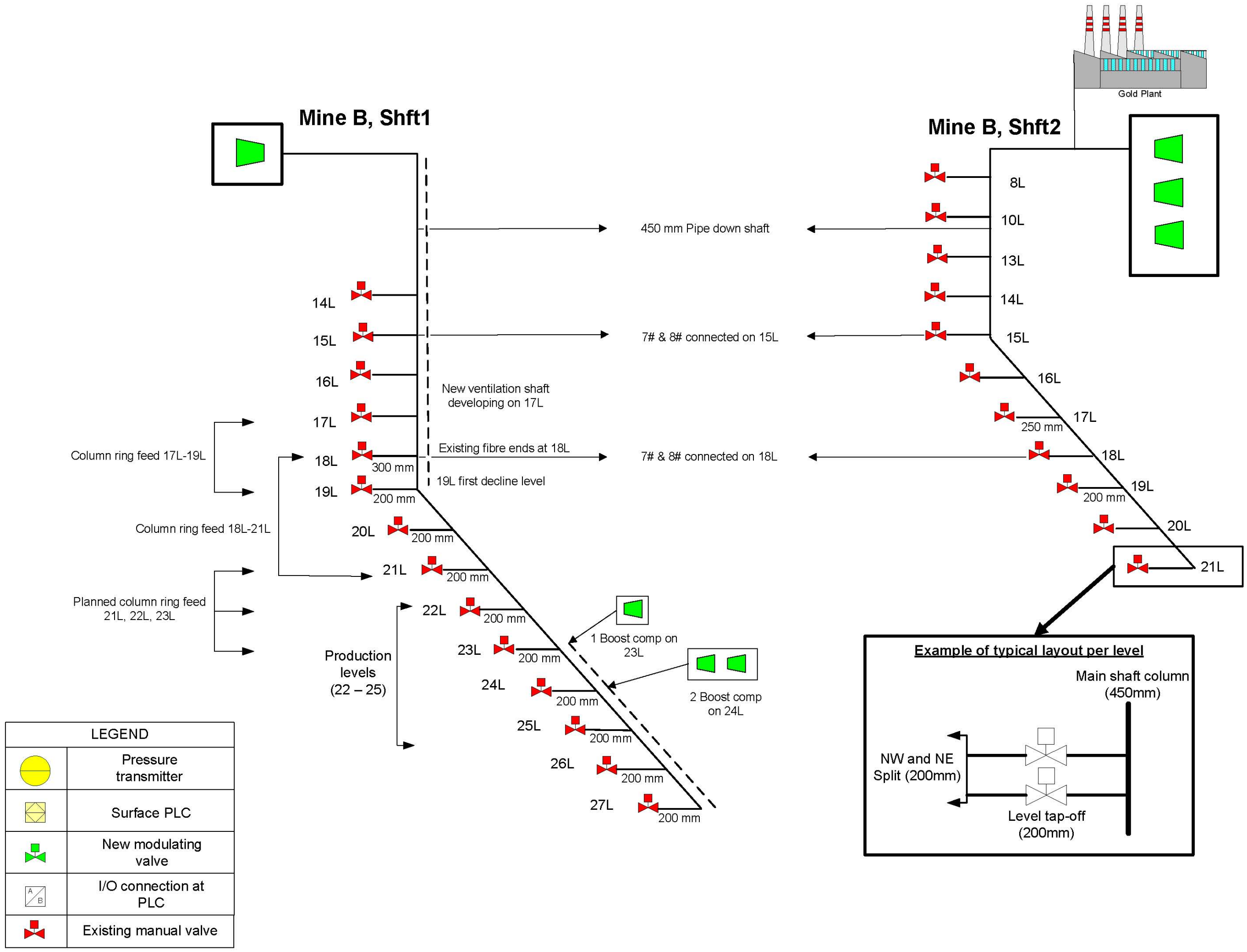

Fig. 7. Simplified underground layout for the air network at Mine B

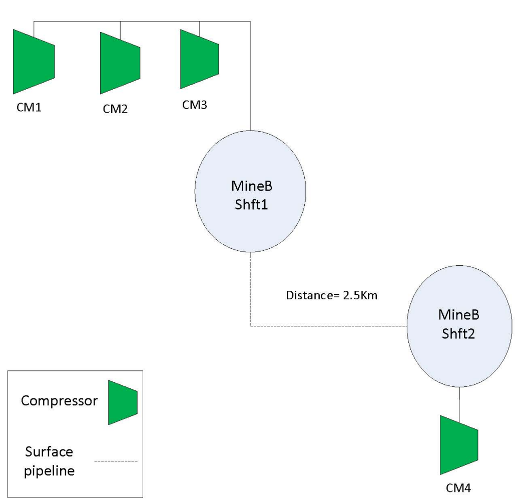

Fig. 6. Surface layout of air network at mine B

B. Mine B Layout

The second mine, B, two shafts are air linked on surface using a 2.5 Km air pipe as shown in Fig. 6. The mine has four compressors, where three of them are located at the first shaft, sht1.

Each of the four compressors has an installed capacity of 2900 kW. Unlike the case of mine A, compressors at mine B have a guide vane control.

As mentioned before the second shaft, sht2 has terminated all production activities, but it is still used to hoist the ore from the fist shaft, sht1 via a skip in the second shaft, sht2. There is still a training center where it uses some air at sht2. At sht1, the production is in full stage, and there, new production levels are being developed.

All the levels have manual valves on all the tap-offs. Note that all the new working levels are in the declined working area as shown in Fig. 7. The 18L, 18-th level, is the link to the declined levels. And shafts, sht1 and sht2 are linked to the level 15L. This is the main line between the two shafts.

The current pressure set point at the compressors is 5.5

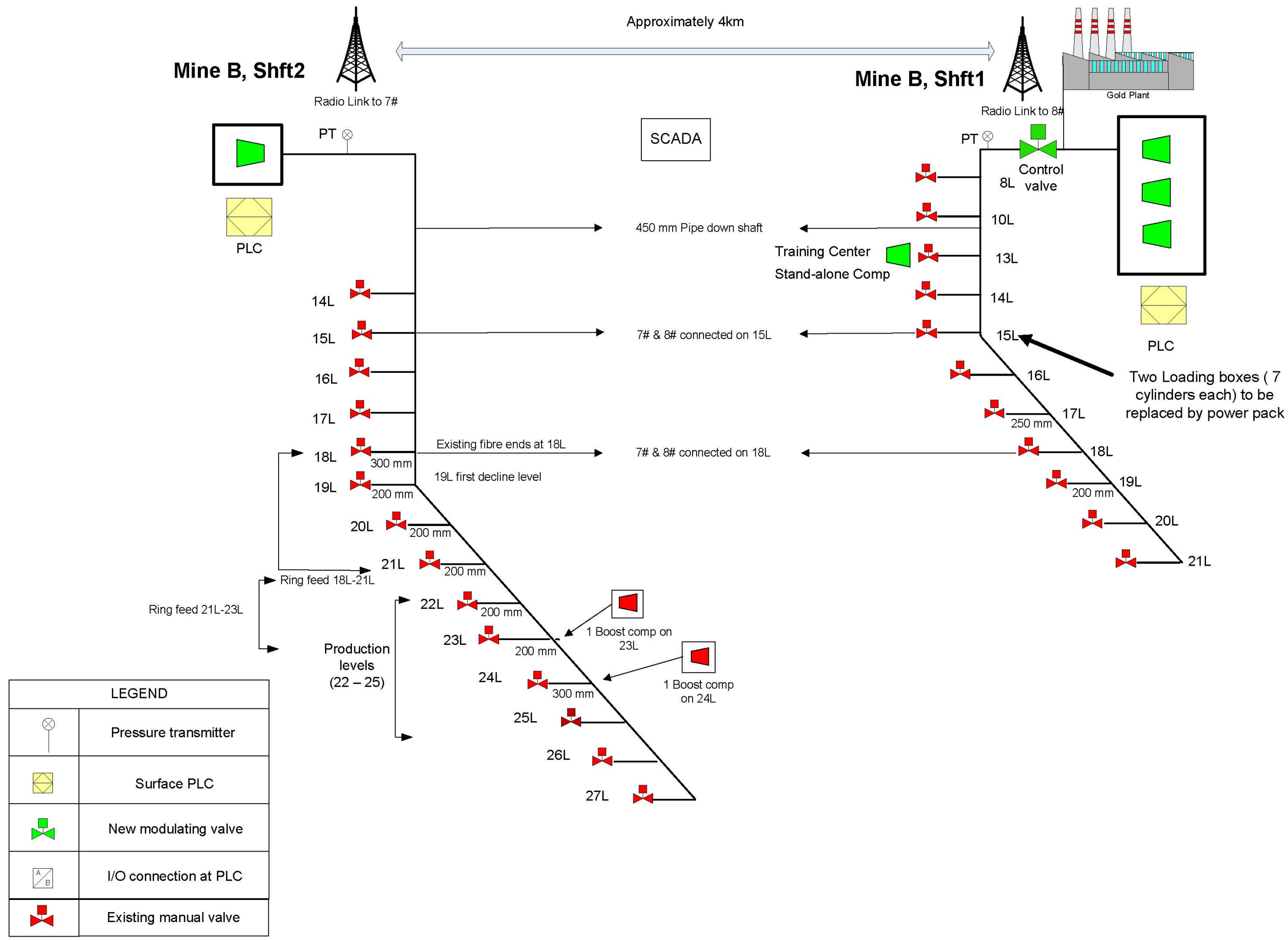

Fig. 8. Mine B proposed control philosophy

kPa, where the drilling requires a minimum of 4.5 kPa. The pressure provided to the development levels is a constant pressure of 4.5 kPa. In the stopping levels it is possible to cut back in the pressure with 2kPa. The mine installed three boosting compressors underground. Two of these compressors are situated at the level 24L and the remaining compressor is situated at the level 23L. At this stage only one compressor per level is used to boost air pressure.

C. Proposed control philosophy

The proposed control philosophy is shown in Fig. 8.

Because mining operations were terminated at the second shaft, sht2, all the manual valves at each level (see the legend) will be blanked off. A control valve will be installed on the main air pipe on the surface. This valve will be throttled to provide a maximum 2 kPa air pressure to the underground. This will provide sufficient pressure to the miners in the underground (refuge bays, pump stations, and loading boxes levels). A stand alone compressor will be installed at the training center at the second shaft, sht2. The air using loading boxes will be replaced with a hydraulic power packs system. This will reduce the air usage at this shaft to the minimum.

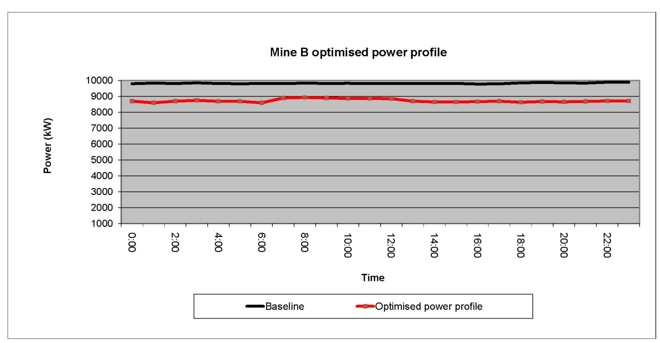

Fig. 9. Optimized power profile for mine B

A PLC will be installed at the compressor.

At the first shaft, sht1, a pressure transmitter will be installed on the main pipe to deliver a maximum and fixed air pressure of 5 bar. A PLC will be installed at the compressor house, which will control the compressor's guide vane to reduce the pressure during the off peak times (No drilling underground).

Both PLCs will communicate with a SCADA system via a radio link. The reason of use of a radio link is to reduce the cost of the control system.

Applying this control philosophy will allow the mine to switch off one compressor permanently. This will result on achieving energy savings and reduce the electricity usage.

D. Proposed results

The mine baseline was determined from data collected from each compressor. Power loggers were installed to compute the power consumed by the compressors at mine B. The baseline and the optimized power profile are shown in Fig. 9.

It can be seen from Fig. 9 that an approximately of a 1.1 MW energy savings is achieved.

IV. Conclusion

As mentioned before in the introduction, an investigation was conducted on each mine to determine the best control philosophy in order to achieve the MW savings target. It was shown that the control philosophy differs for each mine based on the mine status and specifications. These control techniques can be applied on several other mines that have similar production conditions, infrastructure and specifications.

It was also shown that we tried to meet the lowest cost for the control system in order to increase the savings, for instance using fiber optics to link between the different shafts is more efficient than using radio link system. However the relatively long distance between each shaft will require long and high costly fiber optical cables.

In the case of mine A, that the control of the compressors' pressure set points will allow the compressors to cut back. This is done by controlling the guide vane on each compressor. This technique resulted in a 1.13 MW of electricity savings. However this DSM project will have impact during the non-drilling periods. During the drilling time the guide vanes will be fully opened and the compressors will run in full capacity to cover the demand.

In the case of mine B, the control valve units can be used to optimize the compressed air consumption. These units must be controlled and managed from a central point. The SCADA and PLC system can therefore be used for this purpose at mine B. An estimated average load reduction of a 1.1 MW can be achieved at mine B.

References

[1] Georg J. Coakly, "The mineral industry of South Africa", *U.S. Geological Survey Minerals*. Yearbook-2000, 2000.

[2] Department of Minerals and Energy, "Energy Efficiency Strategy of the Republic of South Africa", *Department of Minerals and Energy*, Private Bag X59, Pretoria, 0001, South Africa, Mar. 2005.

[3] DME, DPE, Eskom and SALGA, "National Response to South Africa's Electricity Shortage", Available at: http://www.info.gov.za/otherdocs/2008/nationalresponse_sa_electricty1 .pdf, Last view Jan. 2008.

[4] Statistics South Africa, "Mining: Production and sales", *Statistical release P2041*, Available at: http://www.statssa.gov.za, Postal address: Private BagX44, Pretoria, 0001.

[5] Preliminary energy outlook for South Africa, Energy Research Institute, Dept of Mechanical Engineering, University of cape Town, Private Bag, Rondebosch 7701, October 2001.

[6] J. Matthews, "Seven steps to curb global warming", *Macquarie graduate school of management*, Macquarie University, Sydney NSW 2109, Australia, 2007.

[7] Eskom DSM Website, http://www.eskomdsm.co.za

[8] Department of Minerals and Energy, "Draft Energy Efficiency Strategy of the Republic of South Africa", Private Bag X59, Pretoria, 0001, 2004.

978-1-61284-993-5/11/$26.00 ©2011 IEEE